R. CARDOSO, Citgo Petroleum Corp., Lake Charles, Louisiana;
and **H. Z. KISTER,** Fluor Corp., Aliso Viejo, California

Refinery tower inspections: Discovering problems and preventing malfunctions

A previous survey[1] identified installation mishaps to be one of the top five causes of tower malfunctions. Such malfunctions lead to poor separation, instability, lost capacity and higher energy consumption, all with negative economic impact.

In some cases, a tower may cease to work, forcing a premature outage. Proper inspection following construction and during turnarounds is the best tool to identify installation mishaps, design oversights, fouling and damage, and to correct them before they turn into malfunctions.

This article presents several case histories of refinery towers where inspection and turnaround testing identified potential and actual bottlenecks caused by improper internal installation, inadequate past inspection, fouling and internal damage. In each case, the inspection led to problem identification followed by a simple, low-cost solution.

This article demonstrates that thorough and well-thought-out inspection often prevents a major malfunction in operation. When it comes to towers, you get what you *inspect* (not always what you *expect*).

Case 1: Bad piping for steam inlet line limits tower operation.

A deisobutanizer tower has two horizontal, once-through thermosiphon reboilers in parallel. Both use 250-psig steam with two passes on the heating side. Boil-up was supposed to be regulated by a bottoms temperature controller that indirectly resets the setpoints of both flow control valves (one for each reboiler) in the steam condensate outlet lines (no condensate pot).

Problem. Due to control problems, console operators would not operate the reset control, leaving the steam condensate valves in either manual or auto (flow control only). To maintain product quality (i.e., RVP of the bottom product), the operators would manually adjust the condensate control valve settings. The south reboiler's process-side return line was always colder, consumed less steam and showed no steam condensate level on a sight glass located in the channel head. The north reboiler, even though it consumed more steam, always showed a few inches of steam condensate in the channel head.

Cause. One concern was that the shell side of the south reboiler was severely fouled. It was water-washed online, but with no appreciable improvement in heat transfer.

A damaged pass partition was another possible cause. A field observation revealed an unusual arrangement for the steam supply line to the reboiler (**FIG. 1**). A block valve was located near the bottom of the vertical section of the line, with no provision to drain the steam condensate that would accumulate above the valve when it was closed during a shutdown.

During the reboiler shutdown, steam condensate would accumulate above the block valve. When the valve was opened, a large slug of condensate accelerated and hit the pass partition, causing it to fail. Acceleration of a slug of condensate was much greater during startup because the

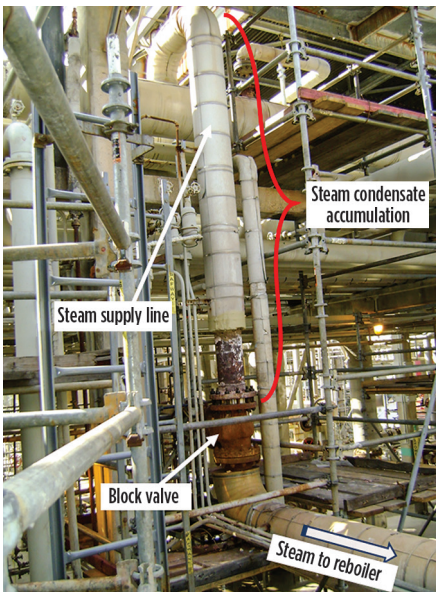


FIG. 1. Steam supply line prone to steam condensate accumulation.

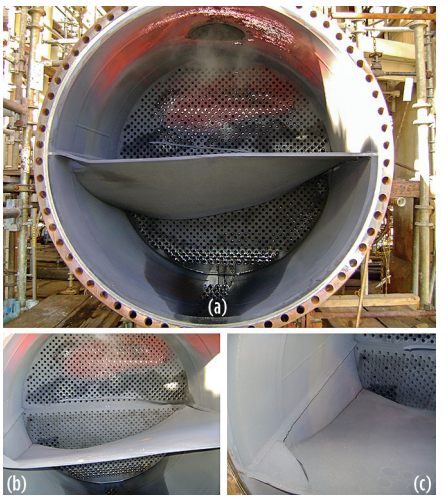


FIG. 2. Damaged pass partition (a) as found once the cover end was removed; and (b, c) details of damaged pass partition.

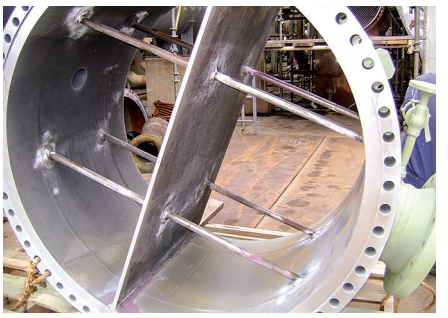


FIG. 3. "Stiffeners" added to avoid future damage to the pass partition plate.

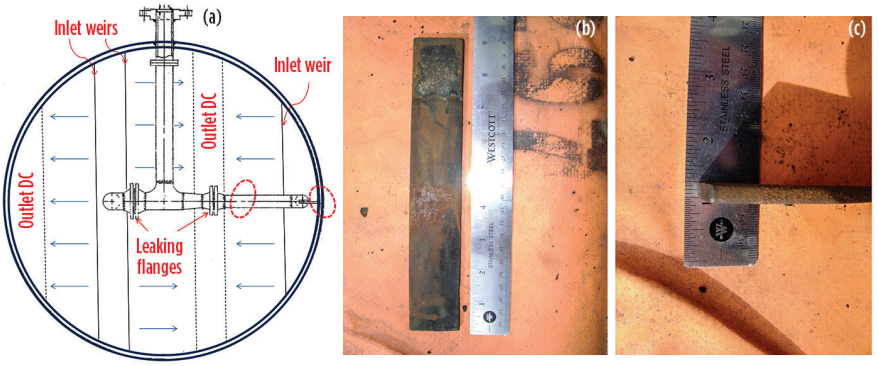


FIG. 4. Reflux distributor with leaking flanges: (a) top view of distributor showing leaking flanges; (b) metallic spacer found between flanges (9 in. long); (c) metallic spacer thickness (0.25 in.).

FIG. 5. Clearance under the downcomer: almost 3 in. where it should be 1.5 in.

cold reboiler (and cold tower bottoms) caused low pressure that increased velocity. FIG. 2 shows the damaged pass partition.

Solution. A steam trap and a drain were installed just upstream of the block valve to remove liquid condensate before the block valve is opened. Some condensate will still accumulate between the drain/steam trap and the gate in the block valve (see FIG. 1), so operators were trained to open the valve slowly to avoid a slug of condensate hitting the pass partition.

Finally, "stiffeners" were installed in the channel head to provide additional strength to the pass partition plate (FIG. 3). The ultimate solution would be the relocation of the block valve and drain/steam trap to the horizontal section of the line leading to the reboiler steam nozzle.

Case 2: Poor installation, inspection lead to poor tray efficiency. An 11.5-ft-inner-diameter deisobutanizer tower equipped with 11 three-pass valve trays in the rectifying section is used to make a high-purity isobutane stream to be recycled to the reaction section of a sulfuric acid alkylation unit. The reflux distributor is arranged such that flow is split: ⅓ and ⅔ to seal areas on the top tray into which it enters behind inlet weirs. Liquid overflowing the inlet weirs feeds the top tray passes (FIG. 4A).

Problem. Process simulation based on plant data indicated that the rectifying trays were 25% efficient, compared to the 90% efficiency expected. The low efficiency caused increased amounts of normal butane in the isobutane product.

Analysis. Three pass trays are highly prone to maldistribution due to their high degree of asymmetry. Many factors could lead to maldistribution of liquid or vapor on these trays. The following may lead to maldistribution of liquid, vapor or both, and therefore account for the lower efficiency:

- Severe fouling hindering valve movement
- Damaged tray panel or collapsed trays
- Different clearances under downcomers, different outlet weir heights, damaged outlet weirs and/or unleveled trays
- Damaged inlet weirs on top tray
- Bad reflux distribution to top tray
- Poor tray balancing or design.

Cause. Turnaround inspection revealed the followings issues:

- Pipe scale was found on the top five trays (a significant amount on the top tray and diminishing from top to bottom). Some construction debris was also found. Approximately 1% of the valves per tray were missing or dislodged.
- Missing or improperly installed seal plates were found
- Misaligned anti-jump baffles were found
- Missing or unfastened downcomer braces were found.

However, the authors believe that the probable causes of the poor tray efficiency were badly leaking flanges in the reflux distributor and/or a bigger clearance under the downcomer:

- **Leaking flanges.** Metallic spacers were found in lieu of gaskets in the flanges (FIG. 4A) of the reflux distributor. These had neither been noted nor corrected in earlier tower inspections. The 0.25-in. gap between the flanges caused a large leak, which induced poor liquid distribution on the top tray. After maldistribution is generated on the top tray, it propagates down the tower in multipass trays, as demonstrated.[2]
- **Clearance under downcomer.** A few trays below the top tray, where clearances were supposed to be 1.5 in., one of the clearances was almost 3 in. (outlet weir height is 2.5 in.) (FIG. 5). The uneven clearances are likely to cause liquid maldistribution between the passes[2] and possible loss of the downcomer seal.

  The bad liquid distribution due to the flange leaks and the high downcomer clearances could have caused vapor to break through the downcomer seal and to flow up the downcomer, as it did in some of the tests for three-pass trays at low liquid loads.[2] As demonstrated in the tests,[2] breaking the seal can lead to a large reduction in tray efficiency. The top section (above the feed tray) operated at low weir loads, ranging from 1.9 to 2.1, and these low values would have been even lower due to the poor reflux distribution.

Results. After replacing the flange spacers with gaskets, adjusting downcomer clearance and taking care of the other minor issues listed, rectifying section tray efficiency was much higher at 81% (compared to 25% before the fix), largely increasing the purity of the overhead isobutane product.

Lesson. Maldistribution in multipass trays often propagates a long way down the tower, causing a large drop in tray efficiency. It follows that for towers containing multipass trays, careful inspection of inter-

nals, especially downcomer clearances and weir heights, is critical to ensure proper liquid and vapor distribution. Internal piping should be built to the same standards as outside piping to avoid internal piping leaks or failures and should be carefully inspected. Flanges and gaskets on internal piping should be carefully checked.

Case 3: Leak test revealing non-evident problem. The bottom section of a deisobutanizer tower equipped with three-pass valve trays has two total liquid draw-off pans connected by two 10-in. balancing lines that feed two once-through thermosiphon steam reboilers. The tower separates isobutane as the top product from a gasoline bottoms with normal butane product recovered as a side draw. The spec on the gasoline is expressed as RVP. A high RVP signifies a large C_4s impurity in the gasoline.

Problem. During normal operation, even at high reboiler steam loads, the butane and isobutane impurity in the gasoline was so high that sometimes the RVP specification was hard to achieve. Higher steam consumption, along with the isobutane losses, accounted for more than $1.5 MM/yr in monetary losses to the refinery.

Cause. The lower temperature of the bottom product compared to the reboiler return, as well as the higher impurity of C_4s in the bottom stream (even at high steam flowrates to reboilers), indicated leakage from the bottom tray or draw-off pans. The leaking liquid would bypass the reboilers and raise the lights content of the bottoms stream. Leakage from the bottom tray or draw pans is a common issue with once-through thermosiphon reboilers.[1,3] At the turnaround, the bottom tray and draw pans were closely inspected visually. The visual inspection did not reveal any integrity problems with the bottom tray panels and/or total liquid draw-off pans.

However, the inspection identified "water marks" indicating leakage from the draw-off pans (FIG. 6). A leak test revealed the real extent of the problem: hoses were used to pour water, and the leakage was so massive that it was not possible to build a liquid level in the draw-off pans (FIG. 7).

During operation, the colder liquid from the bottom tray bypassed the reboilers through the leaking total draw-off pans, cooled the liquid returning from the reboilers and contributed to the high level of C_4s in the bottom product stream.

FIG. 6. Water marks and bottom of draw-off pan identifying the draw pan leaks.

FIG. 7. Leak test revealing a massive leak through the draw pan.

Solution. Initially, replacing gaskets showed some improvement but was not considered to be satisfactory. Seal-welding all of the total draw-off pans in their entirety was the definitive solution.

Lesson. Visual inspection for possible leakage can be misleading. For total draw-off pans, chimney trays, liquid outlet pans, bubble-cap trays and seal areas behind inlet weirs, it is imperative to conduct a leakage test. A leak test is performed by plugging weep holes and then water-filling the pan/tray/seal area up to the top of the weir and measuring how fast the water leaks down. A leakage rate of 1 in. per 20 min for normal services, or as little as 1 in. per hour (or even less) for services where leakage is to be positively avoided, are common criteria used. More details on the leakage test can be found in the literature.[4]

Case 4: Draw pan responsible for poor fractionation and product recovery. The 14.5-ft lower section of the main fractionator for a hydrocracker unit is equipped with two-pass valve trays. Turbine oil is drawn from two liquid outlet pans located just below Tray No. 40 downcomers (FIG. 8). The remaining

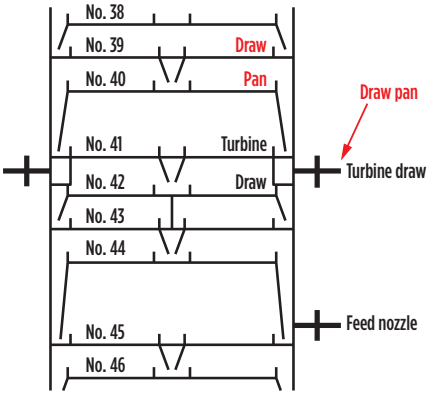


FIG. 8. Section of hydrocracker main fractionator.

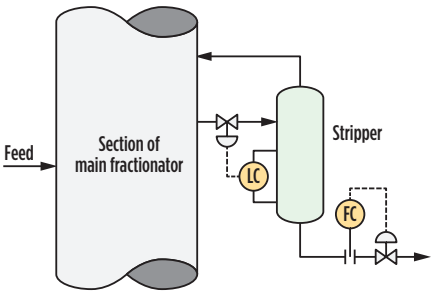


FIG. 9. Simplified scheme of the turbine oil draw system.

liquid is supposed to overflow the draw pan into the four-tray section between the turbine draw nozzles and the two-phase feed inlet. The turbine oil draw proceeds from the main fractionator to a stripper, controlled by the stripper bottom level. A flow controller sets the final production rate from the turbine stripper (FIG. 9).

Problem. Upon attempts to increase the turbine oil draw rate above 19 MMbpd–20 MMbpd, the stripper would start losing level, and the final boiling point of the turbine product would rise considerably. To avoid freezepoint issues induced by high components in the turbine product, the turbine oil production would be reduced, and a considerable amount of turbine oil would be lost with the bottom product.

Cause. Visual inspection of the turbine oil draw sump showed large gaps and no gasket to seal the draw pan (FIG. 10A). A leakage test proved that the draw pans were not capable of holding liquid level. White marks on the wall were the references for the water level in the leakage test, but it was not possible to fill to even those marks (FIG. 10B).

The leaking draw pan, together with

the high product rate, led to drying of Trays No. 41 and No. 42 (leakage bypassed both trays) and maldistribution of liquid to Trays No. 43 and No. 44. Consequently, the separation on Trays No. 41–No. 44 was far worse than design, inducing heavies into the turbine oil product.

Solution. An attempt was made to seal the draw pans with gaskets; however, when the leak test was repeated, no real improvement was observed. The draw pans were then seal-welded, and afterward passed the leak test. Eliminating the leakage improved the valuable turbine oil yield, and also improved the overall efficiency of the four trays between feed inlet and turbine oil draw, thereby reducing the likelihood of high-boiling-point components in the turbine product stream.

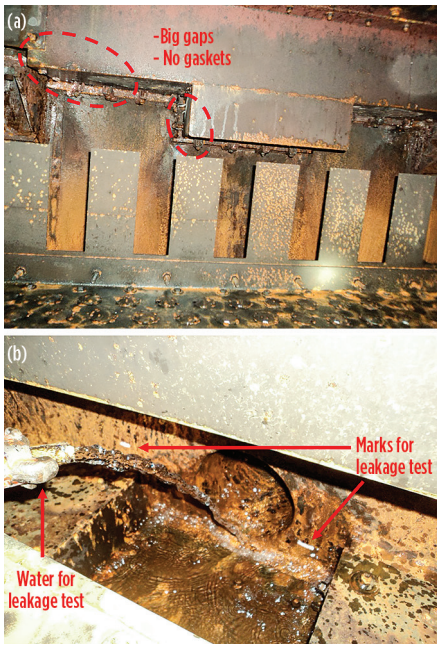


FIG. 10. Turbine oil draw pan: (a) visual inspection showing gaps between pan and support; (b) leakage did not allow water level to reach the white marks.

Case 5: The 6 inches that caused corrosion. In an isomerization unit, the stabilizer tower strips light hydrocarbons and hydrogen chloride from the reactor effluent stream. The overhead system consists of an air-cooled condenser, a water cooler and a receiver drum. All condensate is refluxed to the tower. Light hydrocarbons and hydrogen chloride are sent on pressure control to a downstream caustic scrubber (**FIG. 11**). The entire system (except the scrubber) is kept dry to avoid hydrochloric acid attack.

Problem. Corrosion of the 2-in. drain line and the valve on the receiver drum (which was not normally used) took place a few months after a quick outage, leading to a hydrocarbon leak to the atmosphere and forcing the unit to shut down again to fix the problem.

Cause. During an outage and in preparation for a planned turnaround, an internal rotary inspection system (IRIS) test was performed to determine if the air cooler finned tubes would need to be replaced. This technique introduces water into the overhead system. The receiver (**FIG. 12**) has a 6-in. standpipe in the reflux nozzle, allowing free water to accumulate in the drum during startup and be drained (through a different nozzle) instead of circulating with the reflux. This arrangement (**FIG. 12**) speeds startup by separating and allowing easy removal of free water faster from the system.

The dry-out procedure was executed, and water was observed neither in the liquid samples from the reflux line, nor in the gas samples from the receiver vent line. The drain line was not operated during the startup, so water accumulated in the bottom of the drum and in the drain line.

When the unit was put back into service, the water absorbed small amounts of hydrochloric acid (HCl) and became acidic. A possible mechanism is that in the condenser, the condensed liquid hydrocarbons absorbed small quantities of HCl gas, some of which would later be extracted into the stagnant layer of water at the hydrocarbon–water interface in the drum.

Water that dissolved into the reflux at the hydrocarbon–water interface in the drum would re-vaporize upon entry to the fractionator and would be mostly removed in the vent gas, but the remaining water at the bottom of the drum and in the drainpipe merely increased its acidity and corrosiveness, leading to the leak.

Solution. The dry-out procedure was modified to drain water from the drain line during dry-out.

Lesson. Details are very important. Not being aware of the standpipe possibly caused the drain line to be left in the dry-out procedure. Without a standpipe, the reflux line could be used for draining water and checking for water presence.

Case 6: Tray installation mistake. A 14-ft-inner-diameter debutanizer tower equipped with 40 four-pass valve trays removes light components from the hydrocracker reactor effluent stream before further separation in the main fractionator. The trays are numbered; No. 1 is the top tray.

In the 2006 turnaround, Tray No. 21, just above the feed inlet, was replaced due to corrosion found during the previous internal inspection. Previously, in the 2004 turnaround, the bottom 19 trays—from Tray No. 22 to No. 40—were replaced with duplicates, also because of corrosion.

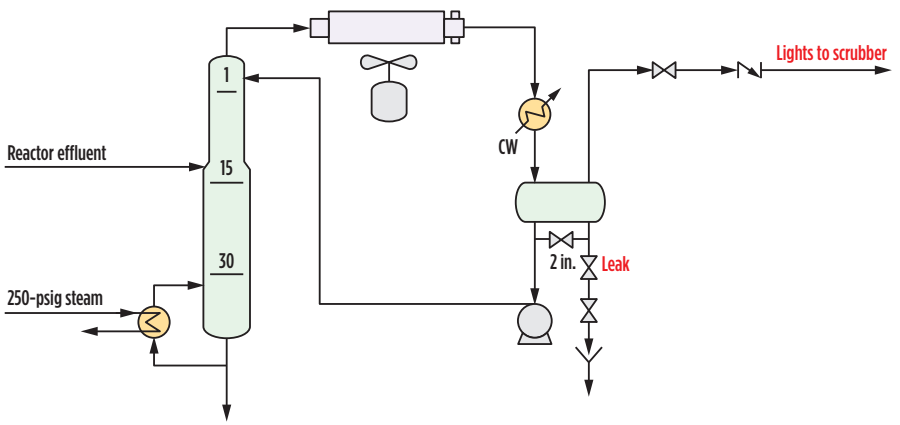


FIG. 11. Schematic of the stabilizer tower.

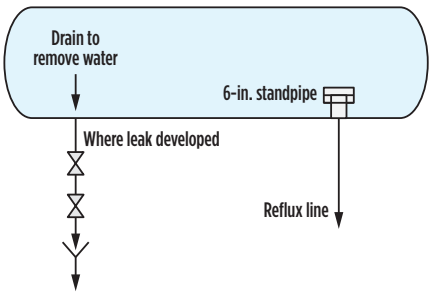


FIG. 12. Sketch of the overhead receiver showing the standpipe and drain.

FIG. 13. Tray No. 21 with inlet weir.

Problem. Upon inspection at a later turnaround, Tray No. 21 was found to have 4-in. inlet weirs less than 0.5 in. away from the downcomer exits. Downcomer panels were freely bowing in and out due to the absence of braces to hold their bottom edges in place (**FIG. 13**). The inlet weirs were not supposed to be there. No other tray had inlet weirs, except for the top tray. Luckily, no operating issues were observed following the installation of new Tray No. 21 in 2006.

Cause. The cause of this improper installation was a misinterpretation of the tray design drawings and a lack of attention to details. The tray drawing for odd trays from No. 1 to No. 21 calls for an inlet weir, but it also specifies that this requirement applies only to Tray No. 1 (top tray for proper distribution of the incoming reflux). The supplier missed that information, and the mistake was not noticed during the post-installation inspection in 2006.

No major operational issues were observed because the liquid load for this section of the tower was low; the authors calculate that at the reduced (0.5-in.) clearance, the head loss of exiting liquid was only about 1.25 in. of liquid, which is on the high side but still within the normal range for downcomers.[4]

Also, with a manhole between Trays No. 20 and No. 21 (and a larger, 42-in. tray spacing), the extra height helped prevent downcomer backup flood. The authors estimate that the downcomers from Tray No. 21 operated at 24% of their maximum downcomer backup capacity. The tower was lucky to "dodge the bullet" of malperformance in this case.

Solution. The inlet weirs were cut and removed from Tray No. 21, and their edges were rounded toward the tray. Braces were installed to attach the downcomer plates to the tray and prevent downcomer bow (**FIG. 14**). The tower performs well.

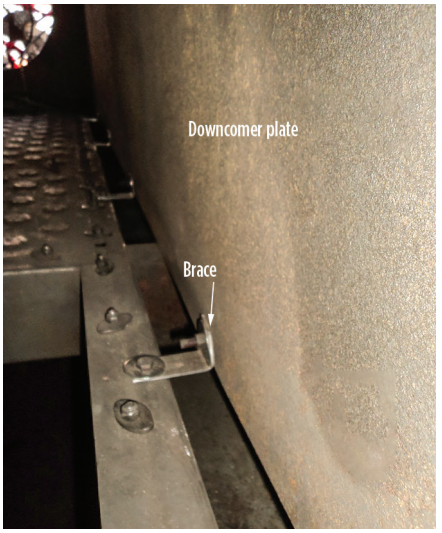


FIG. 14. Solution to tray installation problem.

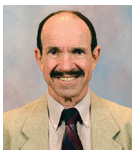
Final thoughts. This article highlights two key lessons for engineers:

- You get what you *inspect,* not what you *expect*
- Correct diagnosis often leads to a correct, low-cost solution
- To achieve trouble-free operation, you need to get dirty! HP

LITERATURE CITED

Complete literature cited available online at HydrocarbonProcessing.com.

RODRIGO CARDOSO is Manager of Process Development for Citgo Petroleum Corp. in Lake Charles, Louisiana. He has 15 yr of experience as a process engineer and has worked as a chemical expert for the federal police in Brazil. Mr. Cardoso holds a BS degree in chemical engineering from Rio de Janeiro Federal University in Brazil and an MS degree from the French Institute of Petroleum in France.



HENRY Z. KISTER is a Fluor Corp. Senior Fellow and the Director of Fractionation Technology. He has more than 30 yr of experience in design, troubleshooting, revamping, field consulting, control and startup of fractionation processes and equipment. He is the author of three books, the distillation equipment chapter in *Perry's Chemical Engineers' Handbook* and more than 120 articles, and has taught the IChemE-sponsored Practical Distillation Technology course more than 500 times in 26 countries. A recipient of several awards, Mr. Kister obtained his BE and ME degrees from the University of New South Wales in Australia. He is a Fellow of IChemE and AIChE, a member of the NAE, and he serves on the Fractionation Research Inc. Technical Advisory and Design Practices Committees.

BORSIG

↘ PROCESS TECHNOLOGY

↘ BALL VALVES

↘ PRESSURE VESSELS AND HEAT EXCHANGERS

www.borsig.de

BORSIG GmbH
Phone: +49 (0)30 4301-01
Fax: +49 (0)30 4301-2236
E-mail: info@borsig.de
Egellsstrasse 21
13507 Berlin
Germany